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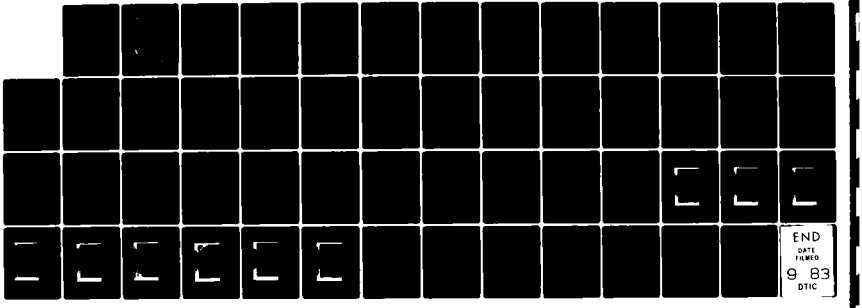

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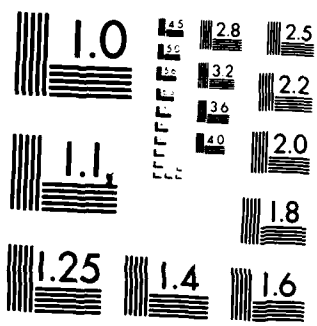

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TECHNICAL REPORT RD-CR-82-12

THE APPLICATION OF COLORGRAPHIC TECHNIQUES TO THE DETERMINATION OF INDIRECT FIRE WEAPONS AIMING POINT STRATEGIES

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Prepared for
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US Army Missile Laboratory

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898

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This research was directed at the utilization of computer-based Decision Support System (DSS) technologies for the generation of aiming point strategies for dynamic indirect fire weapons firing at irregularly shaped target complexes. DSS technology offers an effective human-computer symbiosis in the generation of near optimal solutions to otherwise untractable problems. The project has resulted in the development of a methodology which uses colorgraphic display on a chromatics CG1999 terminal with an internal Z-80

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20. ABSTRACT (cont'd)

microprocessor. The operator can use a light pen to enter target areas of a desired shape, and individual coordinate locations for up to nine weapons. Using internally recorded ballistic data, the operator can then superimpose upon the target area a 95% confidence area ellipse for the expected point of impact and lethal area for each weapon until a solution is found for maximum area coverage. Once a solution is determined, the aiming point grid(s) for each weapon is computed.

SUMMARY

The problems of optimizing expected fractional coverage of an area target when fired upon by indirect fire weapons has been under study for many years utilizing both numerical and simulation techniques. Of necessity, all of these techniques have required two basic ingredients to arrive at a unique, truly optimal solution: an exactly defined target area shape (rectangular, circular, elliptic) and an assumption that all weapons under consideration were firing from essentially the same locations providing identical (assumed) delivery error distribution. In the past, the assumptions were not necessarily unreasonable. However, developing electronic technology will soon provide accurate individual weapon locations, abilities to employ weapons in an increasingly dynamic manner, and sensor capabilities for high resolution target definitions (i.e., exact shapes). These changes may severely test the validity of traditional assumptions and make true optimization of the coverage problem exceedingly difficult, if not impossible, utilizing traditional approaches.

This research was directed at the utilization of computer-based Decision Support Systems (DSS) technology for the development of aiming point strategies for dynamic indirect fire weapons firing upon irregularly shaped targets. DSS technology offers an effective human-computer symbiosis in the development of near optimal solutions to otherwise intractable problems. A methodology was developed using a colorgraphic display which permits the operator to enter target areas of any desired shape and individual (differing) locations for each of up to nine weapons. The operator superimposes upon the target area of 95% Confidence Area Ellipse (for expected point of impact) for each weapon. Following certain placement guidelines for the weapons, the operator eventually arrives at a good solution which tends to maximize expected fractional area coverage. Having arrived at this solution, aiming point grid(s) for each weapon have been computed and aiming point strategy for the given target area is thus available.

A Chromatics CG 1999 computer-graphics terminal with an internal Z-80 microprocessor was utilized in this research. Consequently, computational time is too long for effective use of this laboratory configuration in targeting fleeting targets. However, if the computational portions of the program were performed upon a dedicated microprocessor designed for the purpose and with greater speed, the demonstrated procedure would be time efficient enough to perform in-combat scenarios. This would then enable our artillery to move freely within a dynamic position area and still attack targets of any desired shape in a near optimal manner.

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I. INTRODUCTION

A. Description of the Problem

When attacking an area target with field artillery weapons, the object is to inflict the maximum possible number of casualties or amount of damage to material (maximum target coverage). Given a target area and ideal conditions such as uniformly distributed target elements within the target area, and no projectile delivery errors, then an optimal solution to this problem could be achieved by firing at a set of uniformly distributed points throughout the target area. However, such a set of ideal circumstances does not exist in practice: delivery errors are always present. In light of these nonperfect conditions, the logical approach to the problem of determining optimal aiming point strategies for a given target is to deal with the known probability distributions for these errors and work in terms of expected target coverage. Given a constrained number of rounds for the attack of a specific target, the problem becomes the determination of an aiming point strategy which will maximize the expected coverage of the target area.

B. Objective of the Project

The objective of this project is to develop a procedure which will demonstrate the potential for use of interactive systems colorgraphic technolgy in the selection of aiming point strategies for Army Indirect Fire Weapons, with specific application to the Mulitple Launch Rocket System (MLRS).

C. Scope of the Project

Computational and video display techniques used in this project have been limited to those necessary to demonstrate the potential for colorgraphic Decision Support Systems (DSS) within this problem area. Such refinements as computational subroutines for determination of corrections when firing across grid zone boundaries have not been incorporated into this program due to the fact that such procedures have already been well established and their inclusion in the procedure would have added unnecessary clutter without contributing significantly to the objective. An additional limitation of this project is that although the computational portions of the computer code are standard BASIC computer language, the portions of the code which include the video display commands are peculiar to the Chromatic Colorgraphic 1999 computer which was utilized. As such, this code (contained in Appendix A) should not be used in any other computer without appropriate modifications. A final limitation is that the subroutine which computes the parameters for delivery error distributions and lethal effects patterns is based upon approximate data (not the true classified data) for the MLRS which was provided by Redstone Arsenal, Huntsville, Alabama. These equations and data are discussed in Section IV.

II. LITERATURE REVIEW

A. The Coverage Problem

A review of the literature revealed that a great deal of research and writing has been done on methods of computing expected fractional damage to be achieved by artillery shelling, missiles and bombs. Procedures have been developed for point, linear, and area targets of rectangular, circular, and elliptical configurations. Several reviews of coverage problem literature are available, such as Eckle's "A Survey of Coverage Problems Associated with Point and Area Targets" [Reference 1], and "A Review of the Literature on a Class of Coverage Problems" by Guenther and Terragno [Reference 2]. This thesis benefitted from the extensive literature review of effectiveness studies and computer models conducted by Captain Robert M. Alexander for his Master's Thesis at Georgia Institute of Technology, June, 1977, as well as from his personal notes which were graciously provided prior to his departure.

Of the less numerous papers dealing specifically with the question of optimal aiming point strategy, the following are of particular interest.

An article was written in 1955 entitled "Optimal Ammunition Properties for Salvos" by Walsh [Reference 3]. A salvo is an attack with all weapons aimed at the same aiming point and fired simultaneously. Walsh presents a method for evaluating maximum salvo kill probability and the corresponding optimum round-hit-location probability distribution.

In 1968, Ballistics Research Laboratories published the paper "Expected Target Damage for a Salvo of Rounds with Elliptical Normal Delivery and Damage Functions", by Grubbs [Reference 4]. Grubbs obtained a series expansion for the expected reaction of damage to a circular target when it is assumed that a salvo of n rounds is delivered onto the target area with a non-circular normal distribution and the damage function for each round can be represented by a non-circular exponential square fall-off low.

In "Expected Target Damage for Pattern Firing", [Reference 5] Bressel extended the method introduced by Grubbs to a pattern distribution. He evaluates analytically the damage function for a rectangular target from a firing pattern of n rounds. The delivery errors, mean point of impact and precision error, are both assumed to be non-circular normal and the damage func-tion is defined to be a non-circular exponential square fall-off. Bressel's results were computationally complex and not suitable for manual use, but his work was useful in the later development of computer models capable of evaluating expected coverage for pattern fire.

B. Models

Several computer simulation models have been developed for the purpose of studying the coverage problem. In fact, a large portion of the related literature involves the development and presentation of models. They range from simple effectiveness models that have been developed for programmable pocket calculators [Reference 6] to detailed models such as "FAST-VAL: Target Coverage Model", developed by the Rand Corporation with such lengthy computer run time requirments as to render its use undesirable for studies such as this one [Reference 7].

In 1963, The Operations Evaluations Group, Center for Naval Analysis, presented the Weapons Pattern Effectiveness Model by Westlund and Depoy [Reference 8]. This model employs a Monte Carlo technique to obtain the probabilities of at least any given number of operable hits on a rectangular target. The most desirable characteristic of this model is its capability of analyzing rectangular targets with neither axis parallel to the direction of fire. Unfortunately, the output (probability of a given number of hits) cannot be translated into fractional damage.

A study prepared by Kasper [Reference 9] in 1967 produced a mathematical model and computer program that could be used to determine the fraction of casualties caused by firing rounds at different aiming points in an area target. This model employs a "hit probability distribution" and does not distinguish between precision error and mean point of impact error.

Breaux presented a method for computing expected fractional kill of a circular target in 1967 [Reference 10], followed in 1968 by a method for handling the more general case of an elliptical target, involving both round to round (precision) and occasion to occasion (mean point of impact) errors by Breaux and Mohler [Reference 11]. This method employs Jacobi polynomials to overcome the computational difficulties encountered when the number of rounds are all aimed at the same aiming point. A model by Hess, presented in 1968, is also limited to salvo fire [Reference 12].

Oman developed a method for evaluating coverage functions for the Rand Corporation in 1970 [Reference 13]. This model employs FORMAC, an IBM symbolic mathematical compiler, and the paper was written to demonstrate how FORMAC cound be used to apply a cumbersome mathematical approach to a real world problem. In the model, Oman expressed the probability of destruction in terms of a set of multiple integrations whose initial integrands contain distributions relating to the weapon and the target.

Two models were found in the literature which were considered suitable for this research. These are the BDM Services Company's "The KABOOM Firepower Model", by Porter and Hyams [Reference 14] and Rand Corporation's "A Simplified Weapons Evaluation Model", by Snow and Ryan [Reference 15]. The BDM model uses a Monte Carlo process to generate random draws and varies the distribution errors used to describe the preci-

sions and mean point of impact error deviation. Targets and damage functions are both assumed to be circular. The output of the model is the probability of a kill based on rounds-on-target and the mean and variance of the probability of a kill for a given strategy.

The Rand model was written for research on the use of airpower in support of ground operations. It was modified for a field artillery application by John Bloomquiest of the Army Materiel Systems Analysis Activity (AMSAA). The artillery version is called "SNOW'S QUICKIE". This is a deterministic model for attacking rectangular targets and the output is expected fractional coverage.

SNOW'S QUICKIE was recommended by AMSAA, the sponsor for this research, and is currently being used for weapons effectiveness studies by the Directorate of Combat Development, United States Army Field Artillery School at Fort Sill, Oklahoma. This model was selected for use in this study for several reasons. While the BDM model is limited to circular targets, SNOW'S QUICKIE is designed for the evaluation of rectangular targets, and allows for the description of a wider variety of target shapes. It employs a Gaussian damage function which is elliptic in that probability contours are all ellipses with the same eccentricity. This is more consistent with other artillery research than the circular damage function used in the BDM models. The deterministic simulation of SNOW'S QUICKIE is more efficient for handling the large number of combinations of target size, shape, and delivery error than a Monte Carlo simulation technique would be. And finally, the results of SNOW'S QUICKIE are accepted by the Field Artillery community as evidenced by its current use at Fort Sill. This model is discussed in more detail in Section IV.

III. BACKGROUND DISCUSSION

As seen in Section II, the vast majority of research done in this problem area has attempted to utilize digital computations and/or simulations in arriving at unique, optimal solutions to the problem of selecting aiming points for individual weapons of a firing organization. (This review comes from a thesis [Reference 16] and consists of Chapter 2 extracted in its entirety with corrections to footnote numbers to conform to the document's bibliography). The thrust of these attempts has been to enable the computer to calculate for and dictate to the user, the "best" solution in order to obtain the maximum expected coverage of the target area. The desirability of such a solution in the case of a large area target and a constrained number of rounds is obvious. However, in order to sufficiently constrain the problem for computerized algorithmic solutions, these attempts have required that the particular firing problem conform to several restrictive guidelines such as a circular target or rectangular target perpendicular to the direction of fire, and all weapons firing from essentially the same location providing essentially equal gun-target ranges and parallel directions. These target requirements have always been

unduely restrictive for practical use. Now, in addition, with inevitable near-future changes in tactics and doctrine (utilizing recently developed position location capabilities), individual US Field Artillery weapons will be spread out over large areas and continuously changing positions between firings. As a result, each weapon will have significantly differing expected areas of impact both in size and directional orientation. The dynamic nature of this problem will produce an exceedingly difficult, if not impossible, programming problem for approaches reviewed in Section II. Another aspect of the near-future problem is that of circular or rectangular target requirements, as discussed previously. Here too, evolving technology is providing an increasingly better capability to accurately define a target area. The result is that it may well prove more economical to consider the exact desired target area rather than attempting to cover a larger-than-necessary circle or rectangle encompassing the true target.

With this background in mind, the purpose of this project is to demonstrate the potential for use of interactive colorgraphics to assist (rather than dictate to) the user in arriving at a good solution to a particular firing problem. A "good" solution will be defined as one which tends to maximize the expected coverage of a large area target of any specified shape by any selected number of available weapons firing from different locations. Note that there may be, under this definition, several good and not necesarily "unique-optimal" solutions. This approach is that of a Decision Support System which performs interactively with the user. The DSS requests required information from the user, makes computations based upon user input and then displays the results to the problem graphically. The computer continuously prompts the user to input his decisions concerning methods of attack and improving the current solution. Once the user is satisfied that the currently displayed graphic solution is satisfactory with the constraints of the missile (number of rounds available, urgency/time, etc.) the solution results and aiming point strategy may be sent to the firing units for action. The solution, therefore, is arrived at interactively and allows the flexibility of the human mind to be applied to the problem. This approach eliminates some of the impractical assumptions which are often required to structure the problem for "true" optimal solutions by computerized algorithms or simulations.

The extension of this project into the area of computational optimization, as traditionaly defined, is discussed in Section VI.

IV. DESCRIPTION OF EXPERIMENTAL METHODOLOGY

A. General Procedure

The program developed for this project will conduct the following x-step interactive solution:

1. Ask for and store weapon position using standard military map grids (up to nine weapons A-I).

2. Ask user to define target location and shape, then display target on the screen.

3. Compute and display expected area of impact for each potentially selected weapon to fire based upon the range from its known (stored) location and center of target area. This essentially displays a 95% "confidence area" for expected impact based upon the known error distribution (non-circular, normal) for the particular weapon system. Note that since each weapon is at a significantly different location, each elliptically shaped area will differ in size and orientation.

4. Allow the user to designate, with a light pen, the desired aiming point for a selected weapon. The user's goal should be to place the "confidence areas" so that the maximum number are completely within the target boundaries yet minimize overlap.

5. Upon completion of fine tuning each aiming point, the user specifies that aim point is completed as the aim point grid is displayed upon the screen.

The above procedure is based upon the often used assumptions that individual targets are uniformly distributed throughout the defined target area. Thus, any deviation from the mean point of impact for a particular weapon should still result in a target hit. Overlaps of "confidence areas" would represent potential duplication of effort on targets within this overlap area and will usually be undesirable.

Detailed discussions of several portions of the program appear in the following subsections of this Section.

B. Weapon Position Storage

The first step in running the program requires the user to specify his desires to either conduct a fire mission or update weapon positions. Once he selects the update mode, he specifies which weapon A-I he desires to update. Once specified, the computer displays the current location of the weapon in question and allows the user to update it or merely verify its acccuracy and move on to a choice of selecting another weapon for updating or leaving the update mode. All grids used within the program are to be entered with one meter accuracy: examples are given within the program. This degree of accuracy is based upon the near-future capabilities in weapon position determination and target definition as discussed earlier in Section I.

C. Target Definition

Once the user has specified a desire to conduct a fire mission, the computer requires him to define the target. He must first provide a target

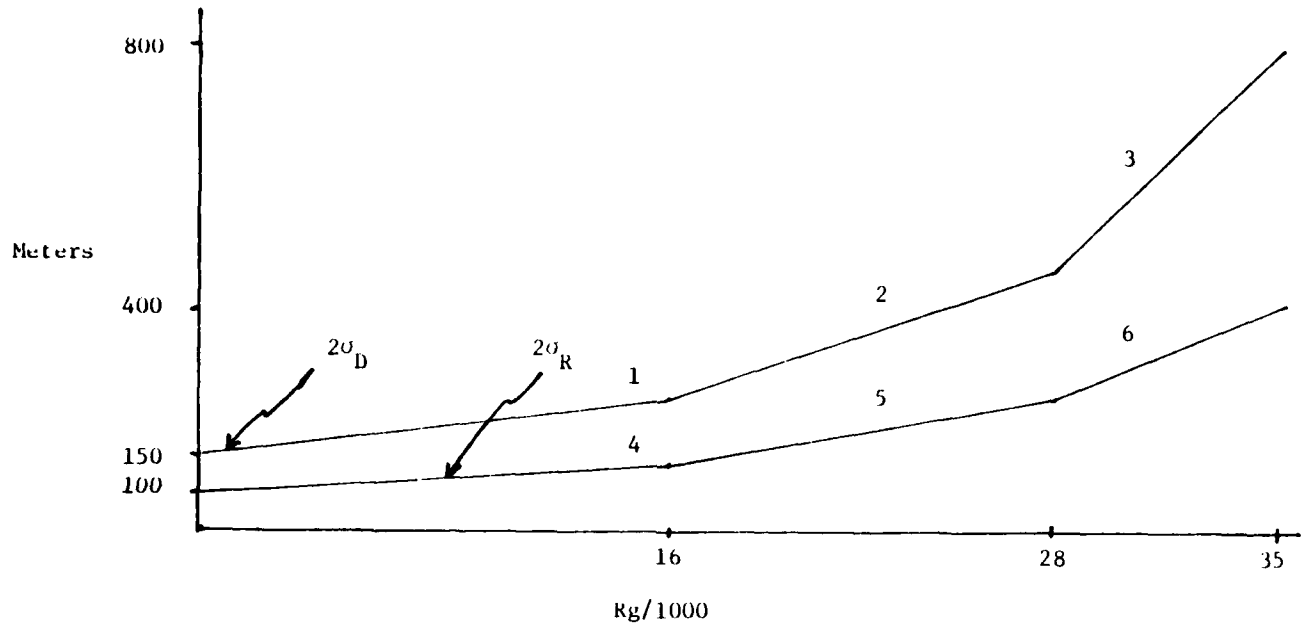
center (one meter accuracy) which serves as a reference point for computations. This grid should be reasonably close to the center of mass for the target area. The user must then specify target shape: circular, rectangular or irregular. In the case of circular or rectangular targets, the computer will prompt the user to provide the radius or attitude (mils), length and width through the keyboard. In the case of an irregular target, the user uses the light pen to specify any desired shapes (assembly area, road, choke point, etc.) utilizing a series of connected vectors. Examples of these target shapes may be seen in Appendix B, Photos 1-3.

One aspect of the target definition not approached in this project, due to the large amount of research yet to be conducted by the Army, is that of determining by what means to define and transmit for video display computer stored maps and associated targets which may appear. Therefore, such targets designated within this program are arbitrary in shape.

D. Parameter Computation and Initial Display

In the conduct of a fire mission, once the user has defined the target area, the program computes and displays the Confidence Area Ellipse (bivariate, normal ellipse displayed in red) and the Effects Pattern Ellipse (deterministic and displayed in black at the center of Confidence Area Ellipse) for each weapon within range of the given target center. These ellipses are computed based upon the range from weapons position to target center and are assumed not to change significantly in size or orientation when positioned near the target boundary. An example of the initial display can be seen in Appendix B, Photo 4.

The parameters for the Confidence Area Ellipse (hereafter referred to as the CAE) and the Effects Pattern Ellipse (EPE) are computed based upon unclassified, approximate data for the MLRS which was provided by Redstone Arsenal. The graphs for the CAE and EPE parameters and their associated estimating equations are depicted in Figures 1 and 2, respectively. The graphs depicted in these figures were constructed based upon end point data from Redstone and represent a hypothetical piecewise linear regression which might be obtained utilizing the true data. The slopes and breakpoints were chosen arbitrarily by the investigator. In the case of the EPE (Figure 2), the data obtained were considered to be deterministic whereas in the case of the CAE (Figure 1) the data were provided in terms of standard deviations for range and deflection - deflection being largest. The relative magnitude of the CAE and EPE parameters presented a problem: a computational scaling factor large enough to allow a 3σ or 4σ CAE to be displayed on the screen would have made the EPE so small (pinpoint) as to have rendered it useless. As a compromise, the following scale was used: the distance between two points on the screen represents 20 meters and a 2σ CAE was utilized as shown in Figure 1. This resulted in a 95.46% CAE. This scaling factor of 20 is also used in computing ranges and grids (max range was chosen to be 35,000 meters).



Seg. 1 $2\sigma_D = 150 + 6.25 \times Rg/1000$

Seg. 2 $2\sigma_D = 250 + 16.66 \times (Rg - 16000)/1000$

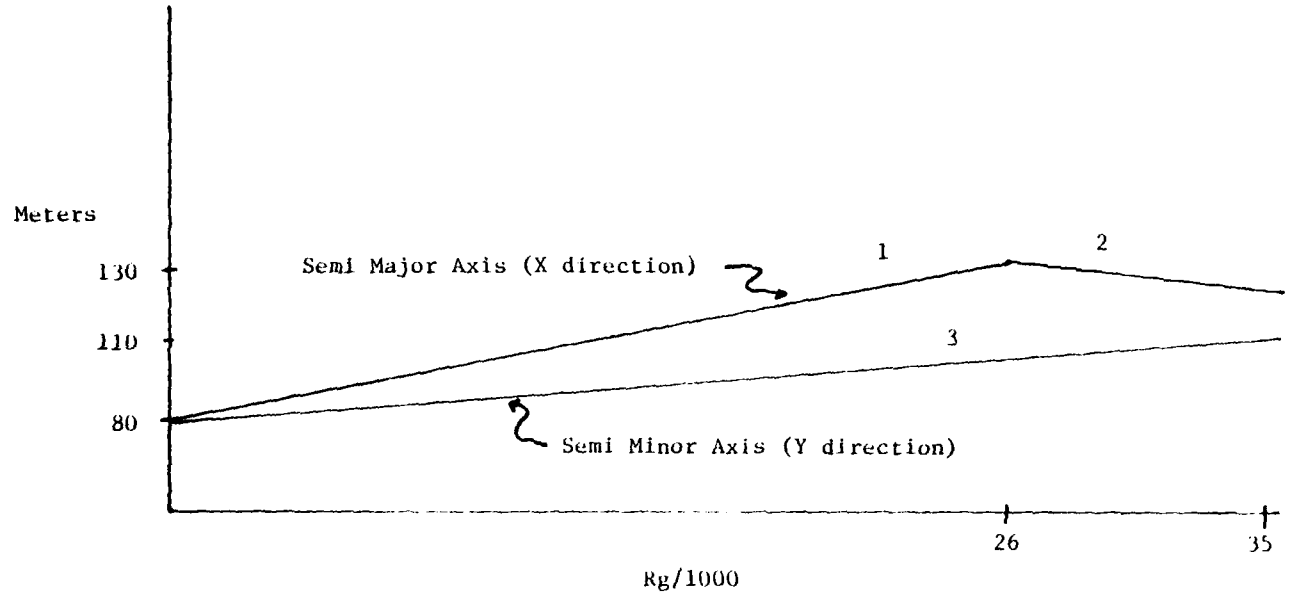
Seg. 3 $2\sigma_D = 450 + 50.0 \times (Rg - 28000)/1000$

Seg. 4 $2\sigma_R = 100 + 3.125 \times Rg/1000$

Seg. 5 $2\sigma_R = 150 + 8.333 \times (Rg - 16000)/1000$

Seg. 6 $2\sigma_R = 250 + 21.428 \times (Rg - 28000)/1000$

Figure 1. Graphs and associated equations defining confidence area ellipse parameters (unscaled values).



Seg. 1 W5 = 80 + 1.923 x Rg/1000

Seg. 2 W5 = 130 - 1.111 x (Rg - 26000)/1000

Seg. 3 W6 = 80 + .857 x Rg/1000

Figure 2. Graphs and associated equations defining effects pattern ellipse parameters (unscaled values).

E. Plot Routines and Subsequent Displays

The plot routines which plot the initial display are the same ones which are utilized in subsequent displays when a weapon's aim point(s) is(are) adjusted from a previous location to another. These plot routines will be discussed in this section.

There are two plot routines, one each for the CAE and the EPE, which are identical except for certain input parameters (semi-major and semi-minor axis). The CAE and EPE have one parameter in common, of course, the center point or aiming point. Both routines take the input parameters and using a loop procedure, compute the boundaries of the ellipse, point by point, as the angle varies from 0 to 2π radians. As each point is computed, the program branches further to another routine: Rotation of axis. This routine takes as input the boundary point from the plot routine and an angle of tilt (computed for each weapon along with the ellipse parameters prior to the initial display) to visualize the proper orientation for the ellipses. The rotation of axis routine converts the point coordinates and returns them to the plot routine where they are plotted in the appropriate color.

Whenever a new location is specified for a particular round (from the weapon being considered), the previous location and associated ellipses are erased. This is done by changing the plot color to be the same as the screen background color prior to entering the plot routines. The new location is then plotted as the program respecifies the appropriate color and enters the same plot routines a second time utilizing the new center grid. If a new round is being designated for the first time, then the erase procedure is skipped and the plot routines are entered immediately to plot the new round.

Once a new plot has been completed, the new grid for the center of the plot is computed by branching to the coordinate conversion routine. This routine computes the grid coordinates by converting the scaled distance from the center of plot to the center of screen, which represents the target center provided at the start of the fire mission. This distance, the scale factor, and angular relationship between the center of screen and aim point are then used to compute the actual grid for the aim point. The new coordinate is then displayed on the screen in one of two places depending upon which type of engagement has been previously specified: multiple weapon/single shot per weapon or single weapon/multiple shot. (This input is required of the user immediately after the initial display). If the user has specified single weapon engagement, the aim points will be updated and listed in the upper left quadrant of the screen. If the user has specified multiple weapon/single shot per weapon engagement, the updated aiming point grids will appear under the appropriate letter A-I at the position of the initial CAE/EPE plots on the border of the screen.

This second method has a recognized limitation in that the number of rounds available to engage one target is limited to the number of weapons within range - a maximum of nine. This was necessary due to space limitations of the screen but was an acceptable compromise in order to demonstrate a multiple weapon approach. Obviously, the most flexible approach would be to allow multiple shots from multiple weapons. Given a larger screen or dual screens (one to plot, one for grids) the techniques used in both methods of engagement discussed above could easily be combined to form the more flexible approach. Sample displays for both methods of approach discussed herein may be seen in Appendix B, Photos 5 & 6. An explanation of variables (to include parameters discussed in this Section) may been seen in Appendix A, just prior to the computer code itself. Finally, a flow diagram for user interaction may be seen in Appendix C.

V. RESULTS AND CONCLUSIONS

The procedure outlined by this document has many desirable capabilities, a few drawbacks requiring further development/study, and potential integration into an interesting system already being developed by the Army. These topics are discussed in this section.

The most desirable characteristic of this procedure was discussed in Section III, Background Discussion: that of providing an alternative approach to a problem which might otherwise be intractable as it is defined. To this end, the objective of the project has been met: demonstrate potential for use of interactive colorgraphics in the problem area. The procedure developed is by no means a finished product ready for fielding. On the other hand, it does combine what the computer does best with what the human does best (pattern recognition and implicit decision making) to form a workable approach to the problem. It is a procedure which may well provide the MLRS with a needed capability and at the same time possibly be applicable to cannon artillery (see Section VI-A).

As with any newly developed procedure, there is always room for improvement. The primary problem with the procedure, as it is written, is that of speed. The problem is found in two areas: the hardware and the computational coding itself. In both cases, the computational speed is the limiting factor. In terms of hardware the microprocessor within the CG 1999 has inherited limited speed due to the differing problems it is designed to handle. A microprocessor designed for the specific problem would, of course, provide greater speed and is easily within the realm of our technology today. With regard to the program itself, there are improvements/refinements which could be made here also, to provide greater speed. For example, the method of moving an ellipse from one point on the screen to another could be greatly improved by computing the boundary points of the tilted CAE/EPE's only once and storing them in matrices. Once stored, the boundary points could be quickly modified by matrix addition of a constant (X or Y deviation corresponding to the old and new

ellipse centers' relative locations on the screen). These matrix operations would be much faster than computing point by point and sending each point to a Rotation of Axis each time the ellipse center is changed. Additionally, plotting a series of precomputed points from a matrix would be much faster than the compute-plot-compute-plot sequence currently being used. These improvements along with expected near-future improvements to hardware should easily make this procedure sufficiently time efficient to attack fleeting targets.

Speed, however, is not the only area of this procedure with room for improvement. The procedure, as it stands now, can be further augmented with some numeric computations to inform the user when he is approaching a desired level of Expected Fractional Coverage. A detailed discussion of the augmentation is contained in Section VI-B.

With the above mentioned improvements, it is quite likely that this procedure will have good potential for use in artillery tactical/technical fire direction. As a result of discussions with the Analysis Branch, Directorate of Combat Developments, US Army Field Artillery School, it has already been identified as having potential for integration into a system which nets the output of many battlefield electronic sensors to provide a real time picture of the battlefield. If incorporated into such a system, an expanded form of this procedure could conceivably greatly aid in selecting which type of weapon and which unit should fire on selected targets. This selection can already be performed by Tacfire provided that the problem conforms to certain definitions such as those discussed before: target shapes, etc. The question for further study, therefore, is how well does Tacfire perform within the problem defined herein?

This question and that of time efficiency are just two of several areas which remain to be investigated. However, there appears to be sufficient reason, as a result of this study, to believe that this procedure warrants some further investigation and comparison to other methods in searching for an optimal method of determining aiming point strategies for weapons firing from a dynamic firing area.

VI. POTENTIAL EXTENSIONS

A. Applications to Cannon Artillery

Although this particular computer code is written based upon approximate data for the MLRS, there is an obvious potential for application to cannon artillery. The MLRS is currently being developed with an on-board navigational system having the accuracy assumed herein. Future cannon weapons may also assume this same capability. Target acquisition and definition capabilities of the future will be just as useful to cannon as to rockets. Therefore, the concept for dealing with the assumed targeting and positioning environment is just as valid for most any indirect fire weapon of the future.

However, there are some cost effectiveness problems involved and these problems may be more critical for the cannon artillery when considered in light of "more boom for the buck". One obvious problem is that of providing the navigational system to the individual cannon: assuming a limited increase in rate of fire, will it be worth the money to equip these cannon in such a manner? Additionally, will the potential savings in ammunition and increase aiming effectiveness of a system such as proposed herein be worth the cost involved when a limited increase in rate of fire is assumed? These are questions of hardware cost effectiveness. There may also be some software/time costs involved for cannon artillery as compared to the MLRS. The most glaring difference in the two weapon systems is that of propellant. The control of total impulse in the MLRS differs significantly from the separate charges tabulated for the cannon. The MLRS data provide for a number of equations (piecewise linear) which are more continuous over the range (elevation) of the weapon. The cannon, of course, have tables of charge and elevations which overlap in range. These will require a more extensive set of equations to describe CAE delivery parameters or an extensive set of "look-up" matrices - either of which may cause time problems in executions. However, given the appropriate effort, all of these software problems may be solved at a reasonable cost.

Of all of the above problems, the materiel cost effectiveness problem will most likely be the worst. Setting the considerations aside, it would appear that the concept proposed herein has definite potential for improving the flexibility of cannon artillery aiming point strategies.

B. Numerical Optimization Procedures

As discussed earlier, methods reviewed in Section II are not applicable to this problem as it is defined in Section III. One of the target obstacles to solution by traditional means is that of varying delivery error distributions due to differing weapon locations. This particular aspect of the problem can be eliminated if a target is engaged utilizing the Single Weapon Method of Engagement. Furthermore, if either of the two target shapes, circular or rectangular, are used, the techniques discussed in Section II provide closed form solutions since the problem has been simplified to its original form. In this case, this procedure may be useful only in determining which weapon is best suited for attacking the target.

At this time, indications from Combat Development US Field Artillery School, Fort Sill, are that the MLRS weapon system will be employed in the manner just described (one weapon per target) whenever possible. However, the problem of computing a closed form solution for just one weapon still remains when the target is of an irregular shape. In this case, should a numerical approach be considered for comparison to this graphical method, one option would be to subdivide the irregular target into several standard shapes (circular, elliptical, or rectangular) and subsequently solve the several smaller problems using the approaches of Section II. Another

option would be a Nonlinear Programming approach in which linear approximations of target boundary segments are utilized to form a convex set within which an objective function based upon the Confidence Area Ellipse for the desired weapon can be maximized. Such an objective function would maximize the expected coverage by maximizing the number of aiming points within the convex area while imposing penalites (negative terms) for CAE's which overlap. At this time, it is unclear (and a subject for further study) what results such a comparison of this graphical procedure and the above discussed numerical approximation procedures would yield in terms of time and accuracy tradeoffs.

The above discussed approximation procedures could be used, as stated, if only one weapon were being considered. However, there are instances which may arise, in which more than one weapon is required. One such example would be, in the case of the MLRS, when no one weapon within range has a sufficient number of rounds available to attack a target. Another such case would be for cannon artillery, which will not, even in the near future, have rates of fire high enough to permit single weapon engagement. (This, of course, assumes the cost effectiveness studies prove this graphical approach useful for cannon artillery). In such instances, the numerical approximation procedures suggested above would be greatly expanded in scope as the number of differing delivery error distributions increases. With this in mind, a numerical augmentation to this graphical approach could be considered as an alternative to the approximate methods.

Such a numerical augmentation would be to provide the user with an updated readout of the Expected Fractional Coverage (Expected Coverage/Target Area) each time an aim point is added. Such computations would involve additional hardware features which would count the number of dots on the screen which would be within an intersection of two or more CAE's or the number of dots within a CAE which lie beyond the target boundary. Such a capability would provide a means for computing the probabilities involved in the negative terms of the Expected Coverage summation (subtracting out intersections). In this manner, exact Expected Coverage could be calculated using involved subroutines or lower bounds could be computed by not adding the grand intersection terms into the expected coverage summation: a less involved computation.

For example, consider CAE1, CAE2, and CAE3 which all intersect and have differing EPE's. Now, letting * represent the intersection operation, and CAE's/EPE's represent areas on the screen, then

$$\begin{matrix}\text{Expected} \\ \text{Coverage}\end{matrix} = (EPE1 + EPE2 + EPE3).95$$

$$- \frac{CAE1*CAE2}{CAE1} (EPE1) + \frac{CAE1*CAE2}{CAE2} (EPE2) \quad .95$$

$$- \frac{CAE2*CAE3}{CAE2} (EPE2) + \frac{CAE2*CAE3}{CAE3} (EPE3) \quad .95$$

$$- \frac{CAE1*CAE3}{CAE1} (EPE1) + \frac{CAE1*CAE3}{CAE3} (EPE3) \quad .95$$

$$+ .95 \frac{CAE1*CAE2*CAE3}{CAE1} (EPE1) + \frac{CAE1*CAE2*CAE3}{CAE2} (EPE2)$$

$$+ \frac{CAE1*CAE2*CAE3}{CAE3} (EPE3)$$

or Expected Coverage $\doteq$ same as above less last term. Once the Expected Coverage is computed, forming the ratio Expected Coverage/Target Area would yield the Expected Fractional Coverage as of the last round placed. Using this readout, the user could add/shift aim points until the desired expected fractional coverage is achieved.

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Appendix A

Variable List and Computer Code

VARIABLE NAMES AND EXPLANATIONS

S$	Temporary variable used to accept alphabetic choices from the user
C	Temporary variable used to accept numeric choices from the user
TX, TY	X-Y coordinates for target center
_X, _Y	Where _ is A-I. X, Y coordinates for wpn A-I location
WX, WY	Temporary variable for a wpw location for use in calculations. Eg: WX = BX, WY = BY, then calculation subroutine utilizing WX, WY
XD, YD	Deviations between 2 pts in X and Y directions
WR	Range to tgt for wpn of concern
WF	Az of fire for wpn of concern
_F	Where _ is A-I. Az of fire for wpn A-I to current tgt. Eg: after WR computed based on TX, TY, WX, WY, then BF = WF
WT	Az of tilt (directional orientation) for wpn of concern ellipses
_T	Where _ is A-I. Az of tilt for A-I ellipses
_1, _2	Where _ is A-I. X, Y coordinates for center of most recent CAE, EPE plots for wpn A-I
T1, T2	Temporary storage for X, Y coordinates for center of next plot of CAE, EPE until most recent plot is erased (input by light pen). Also X, Y screen coordinates for interactive choices by light pen.
P1, P2	X, Y coordinates for any ellipse being plotted by plot subroutine. Eg: P1 = A1, P2 = A2 then enter plot routine
_3, W3	Permanent and temporary variables for wpn A-I. Equals 2 std deviations in deflection for CAE. Eg: W3 = F(WR), then _ 3 = W3 (scaled values)
_4, W4	Same relationships as _3, W3 except equals 2 std deviations in range for CAE
_5, W5	Same as above except semi-major AXIS for EPE
_6, W6	Same as above except semi-minor AXIS for EPE
P3...P6	Temporary variables (as described above) for any ellipse being plotted

VARIABLE NAMES AND EXPLANATIONS (cont.)

Sequence	WR = f(XD, YD) (say for wpn B) Eg: W3 = f(WR); W4 = F(WR); W5 = f(WR); W6 = f(WR) B3 = W3; B4 = W4; B5 = W5; B6 = W6 (permanent storage) P1 = BX; P2 = By; P3 = B3; P4 = B4; P5 = B5; P6 = B6; PT = BT then plot using "P" variables
PX, PY	Final grid for an aim point for display on screen. PX, PY = f(TX, TY, P1, P2)
PN	Variable for numbering aiming points within single wpn adjustment routine. Also used in positioning cursor for printing PX, PY
TH	Angle in radian (0 - 2π) within plot routine
XT, YT	A computed point on a CAE or EPE before tilting. Using in plot routine
XP, YP	Point on CAE or EPE after correction for tilt. Is output from Rotation of Axis Routine. XP, YP = f(XT, YT, PT). Returned to plot routine to be plotted.

COMPUTER CODE

```
1  PRINT"~X5,~Y5,~C4~U060491INDIRECT FIRE~U075421AIMING POINT~U060351COLORGRAPHICS"
2  PRINT"~X1,~Y1,"
3  PRINT"~C2~U150250PRESENTED BY:~C7~U248250CPT JOHN G. SWEENEY,JR~U248238M.S.O.R.
CANDIATE,IE CALLAHAN,ADVISOR,~C7 GEORGIA TECH"
4  PRINT"~U248230COL(USA RET.)~C1~U248190DR.DONOVAN YOUNG,ADVISOR,~C7   GEORGIA TECH"
5  DEFSTR S:PRINT"~U050050 ENTER   C   TO RUN THE PROGRAM":INPUT S$
6  IF S$="C" THEN 10 ELSE GOTO 10
10 REM SETUP AND CHOICE OF OPN
20 PRINT"~W000,511,511,450,~M~C7~N~C4"
30 PRINT CHR$(12);CHR$(27);"OA1";"~W000,449,511,000,~M~C1~N~C4"
40 PRINT CHR$(12);CHR$(27);"GA0";CHR$(28):PI=3.14159
45 Z$=CHR$(27):E$=CHR$(12):DEFSTR S:C$=CHR$(21):L$=CHR$(10)
50 PRINT"ENTER  1  FOR MISSION  2   TO UPDATE WPN PSNS."
60 INPUT C
70 IF C=1 GOTO 230
80 PRINT"SPECIFY 1 WPN, A-I, OR TYPE *COMPLETE* FOR NO MORE UPDATES.":INPUT S$
90 IF S$="A"THEN 125 ELSE IF S$="B"THEN 135 ELSE IF S$="C"THEN 145
91 IF S$="D"THEN 155 ELSE IF S$="E"THEN 165 ELSE IF S$="F"THEN 175
92 IF S$="G"THEN 185 ELSE IF S$="H"THEN 195 ELSE IF S$="I"THEN 205
93 IF S$="COMPLETE"THEN 120
100 PRINT E$;"INPUT ERROR- REENTER":GOTO 80
110 PRINT
120 PRINT E$:GOTO 50
125 PRINT E$;"CURRENT A PSN IS  ";AX,AY
130 PRINT"INPUT X,Y FOR A- EX 45623,74321":INPUT AX,AY:PRINT E$:GOTO 80
135 PRINT E$;"CURRENT B PSN IS  ";BX,BY
140 PRINT"INPUT X,Y FOR B- EX 45623,74321":INPUT BX,BY:PRINT E$:GOTO 80
145 PRINT E$;"CURRENT C PSN IS  ";CX,CY
150 PRINT"INPUT X,Y FOR C- EX 45623,74321":INPUT CX,CY:PRINT E$:GOTO 80
155 PRINT E$;"CURRENT D PSN IS  ";DX,DY
160 PRINT"INPUT X,Y FOR D- EX 45623,74321":INPUT DX,DY:PRINT E$:GOTO 80
165 PRINT E$;"CURRENT E PSN IS  ";EX,EY
170 PRINT"INPUT X,Y FOR E- EX 45623,74321":INPUT EX,EY:PRINT E$:GOTO 80
175 PRINT E$;"CURRENT F PSN IS  ";FX,FY
180 PRINT"INPUT X,Y FOR F- EX 45623,74321":INPUT FX,FY:PRINT E$:GOTO 80
185 PRINT E$;"CURRENT G PSN IS  ";GX,GY
190 PRINT"INPUT X,Y FOR G- EX 45623,74321":INPUT GX,GY:PRINT E$:GOTO 80
195 PRINT E$;"CURRENT H PSN IS  ";HX,HY
200 PRINT"INPUT X,Y FOR H- EX 45623,74321":INPUT HX,HY:PRINT E$:GOTO 80
```

```
205 PRINT E$;"CURRENT I PSN IS  ";IX,IY
210 PRINT"INPUT X,Y FOR I- EX 45623,74321":INPUT IX,IY:PRINT E$:GOTO 80
220 REM *** DEFINE TARGET
230 PRINT E$;"INPUT X,Y TGT CENTER  EX 45623,74321":INPUT TX,TY:PRINT E$
240 PRINT"INPUT TGT SHAPE  0  FOR CIRCLE  1  FOR RECTANGLE  2 FOR IRREG.":INPUT TS
250 IF TS=0 THEN 300 ELSE IF TS=2 THEN 2430
251 PRINT"INPUT ATTITUDE(MILS),LENGTH,WIDTH  EX 2750,1200,800"
260 INPUT TB,TL,TW:PRINT E$:TA=TB/17.8*3.14159/180:RA=ATN(TL/TW):P1=255:P2=255:PT=TA
270 RD=SQR((TW/40)^2+(TL/40)^2):X1=RD*SIN(RA):Y1=RD*COS(RA):X2=RD*SIN(PI-RA)
271 Y2=RD*COS(PI-RA):X3=RD*SIN(PI+RA):Y3=RD*COS(PI+RA):X4=RD*SIN(2*PI-RA)
272 Y4=RD*COS(2*PI-RA):XT=X1:YT=Y1:GOSUB1800:X1=XP:Y1=YP:XT=X2:YT=Y2:GOSUB1800:X2=XP
273 Y2=YP:XT=X3:YT=Y3:GOSUB1800:X3=XP:Y3=YP:XT=X4:YT=Y4:GOSUB1800:X4=XP:Y4=YP
280 PRINT Z$;"OA1";"~C7~G("
281 PLOT X1,Y1,X2,Y2,X3,Y3,X4,Y4,X1,Y1:PRINT C$;"~C4";Z$;"OA0"
282 PRINT E$:GOTO 321
290 REM *** CIRCULAR TARGET
300 PRINT E$;"INPUT TGT RADIUS-METERS":INPUT TT:TR=TT/20:PRINT Z$;"OA1"
310 PRINT "~C7~G*":PLOT 255,255,TR:PRINT C$;"~C4";Z$;"OA0";E$
320 REM *** COMPUTATION AND PLOT OF INITIAL DISPLAY ELLIPSES
321 PI=3.14159:PP=2*PI+PI/6:D=PP/36:PN=1
330 IF AX=0 THEN 370 ELSE PRINT Z$;"OA1"
340 WX=AX:WY=AY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 370 ELSE A1=50:A2=210:A3=W3:A4=W4
341 A5=W5:A6=W6:AT=WT
350 P1=A1:P2=A2:P3=A3:P4=A4:P5=A5:P6=A6:PT=AT:GOSUB1700:PRINT"~C0":GOSUB1750
360 PRINT Z$;"OA1";"~U050210A"
370 IF BX=0 THEN 410 ELSE PRINT Z$;"OA1"
380 WX=BX:WY=BY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 410 ELSE B1=50:B2=130:B3=W3:B4=W4
381 B5=W5:B6=W6:BT=WT
390 P1=B1:P2=B2:P3=B3:P4=B4:P5=B5:P6=B6:PT=BT:GOSUB1700:PRINT"~C0":GOSUB1750
400 PRINT Z$;"OA1";"~U050130B"
410 IF CX=0 THEN 450 ELSE PRINT Z$;"OA1"
420 WX=CX:WY=CY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 450 ELSE C1=50:C2=50:C3=W3:C4=W4
421 C5=W5:C6=W6:CT=WT
430 P1=C1:P2=C2:P3=C3:P4=C4:P5=C5:P6=C6:PT=CT:GOSUB1700:PRINT"~C0":GOSUB1750
440 PRINT Z$;"OA1";"~U050050C"
450 IF DX=0 THEN 490 ELSE PRINT Z$;"OA1"
460 WX=DX:WY=DY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 490 ELSE D1=150:D2=50:D3=W3:D4=W4
```

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460 D5=W5:D6=W6:DT=WT
470 P1=D1:P2=D2:P3=D3:P4=D4:P5=D5:P6=D6:PT=DT:GOSUB1700:PRINT"~C0":GOSUB1750
480 PRINT Z$;"0A1";"~U150050D"
490 IF EX=0 THEN 530 ELSE PRINT Z$;"0A1"
500 WX=EX:WY=EY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 530 ELSE E1=250:E2=50:E3=W3:E4=W4
501 E5=W5:E6=W6:ET=WT
510 P1=E1:P2=E2:P3=E3:P4=E4:P5=E5:P6=E6:PT=ET:GOSUB1700:PRINT"~C0":GOSUB1750
520 PRINT Z$;"0A1";"~U250050E"
530 IF FX=0 THEN 570 ELSE PRINT Z$;"0A1"
540 WX=FX:WY=FY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 570 ELSE F1=350:F2=50:F3=W3:F4=W4
541 F5=W5:F6=W6:FT=WT
550 P1=F1:P2=F2:P3=F3:P4=F4:P5=F5:P6=F6:PT=FT:GOSUB1700:PRINT"~C0":GOSUB1750
560 PRINT Z$;"0A1";"~U350050F"
570 IF GX=0 THEN 610 ELSE PRINT Z$;"0A1"
580 WX=GX:WY=GY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 610 ELSE G1=450:G2=50:G3=W3:G4=W4
581 G5=W5:G6=W6:GT=WT
590 P1=G1:P2=G2:P3=G3:P4=G4:P5=G5:P6=G6:PT=GT:GOSUB1700:PRINT"~C0":GOSUB1750
600 PRINT Z$;"0A1";"~U450050G"
610 IF HX=0 THEN 650 ELSE PRINT Z$;"0A1"
620 WX=HX:WY=HY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 650 ELSE H1=450:H2=130:H3=W3:H4=W4
621 H5=W5:H6=W6:HT=WT
630 P1=H1:P2=H2:P3=H3:P4=H4:P5=H5:P6=H6:PT=HT:GOSUB1700:PRINT"~C0":GOSUB1750
640 PRINT Z$;"0A1";"~U450130H"
650 IF IX=0 THEN 690 ELSE PRINT Z$;"0A1"
660 WX=IX:WY=IY:GOSUB1390:GOSUB1580:IF WR>33000! THEN 690 ELSE I1=450:I2=210:I3=W3:I4=W4
661 I5=W5:I6=W6:IT=WT
670 P1=I1:P2=I2:P3=I3:P4=I4:P5=I5:P6=I6:PT=IT:GOSUB1700:PRINT"~C0":GOSUB1750
680 PRINT Z$;"0A1";"~U450210I"
690 REM *** SELECTION OF SINGLE OR MULTIPLE WPN ENGAGEMENT
700 PRINT Z$;"0A0";E$;"SELECT METHOD OF ENGAGEMENT"
702 PRINT"~C1~F~G+":PLOT 100,465,140,488,210,465,250,488:PRINT C$;"~L~C4"
704 PRINT"~U143495MULTIPLE~U143483WPN~U253495SINGLE~U253483WPN":GOSUB2350
706 IF(T1<140)*(T1>100)THEN 720 ELSE IF(T1<250)*(T1>210)THEN 1050:GOTO 700
720 REM *** MULTIPLE WPN ENGAGEMENT - ADJUSTMENT PHASE
730 GOSUB 2530
740 IF(T1<46)*(T1>16)THEN790 ELSE IF(T1<92)*(T1>62)THEN610
741 IF(T1<138)*(T1>108)THEN630 ELSE IF(T1<184)*(T1>154)THEN650
742 IF(T1<220)*(T1>190)THEN670 ELSE IF(T1<266)*(T1>236)THEN890
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743 IF(T1<311)*(T1>282)THEN910 ELSE IF(T1<357)*(T1>327)THEN930
744 IF(T1<403)*(T1>373)THEN950 ELSE IF(T1<479)*(T1>419)THEN1000 ELSE GOTO730
750 REM *** WPN A MULTIPLE ENGAGEMENT
790 GOSUB1820:PRINT"~U050210";L$;PX;"~U050210";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO790
800 REM *** WPN B MULTIPLE
810 GOSUB1680:PRINT"~U050130";L$;PX;"~U050130";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO810
820 REM *** WPN C
830 GOSUB1950:PRINT"~U050050";L$;PX;"~U050050";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO830
840 REM *** WPN D
850 GOSUB2020:PRINT"~U150050";L$;PX;"~U150050";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO850
860 REM *** WPN E
870 GOSUB2080:PRINT"~U250050";L$;PX;"~U250050";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO870
880 REM *** WPN F
890 GOSUB2130:PRINT"~U350050";L$;PX;"~U350050";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO890
900 REM *** WPN G
910 GOSUB2190:PRINT"~U450050";L$;PX;"~U450050";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO910
920 REM *** WPN H
930 GOSUB2240:PRINT"~U450130";L$;PX;"~U450130";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO930
940 REM *** WPN I
950 GOSUB2290:PRINT"~U450210";L$;PX;"~U450210";L$;L$;PY;Z$;"DA0":GOSUB970:GOTO950
960 REM *** DECISION:CONTINUE ADJ THIS WPN OR MOVE TO NEW WPN-SUBROUTINE
970 PRINT E$;"CONTINUE THIS WPN?   ADJ NEW WPN?   ALL WPNS COMPLETE?"
972 PRINT"~C1~F~G+":PLOT57,473,97,490,214,473,254,490,351,473,391,490:PRINT C$
974 PRINT"~C4~L~U057472CONTINUE~U214472NEW~U351472COMPLETE":GOSUB2350
976 IF(T1<97)*(T1>57)THEN RETURN ELSE IF(T1<254)*(T1>214)THEN 980
977 IF(T1<391)*(T1>351)THEN 1000 ELSE GOTO970
980 PRINT E$:GOTO 730
990 PRINT
1000 REM *** MISSION TERMINATION SUBROUTINE
1010 PRINT
1020 PRINT Z$;"DA0";E$;"THIS COMPLETES AIMING PT ADJUSTMENTS. TYPE DONE TO ERASE ";
1030 PRINT"THE SCREEN AND PREPARE FOR ANOTHER MISSION.":INPUT S$
1040 IF S$="DONE" THEN 10 ELSE GOTO 1020
1050 REM *** SINGLE WPN ENGAGEMENT SUBROUTINE
1060 PN=1
1070 GOSUB2530
1071 IF(T1<46)*(T1>16)THEN1120 ELSE IF(T1<92)*(T1>62)THEN1140
1072 IF(T1<138)*(T1>108)THEN1160 ELSE IF(T1<184)*(T1>154)THEN1180
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1073 IF(T1<220)*(T1>190)THEN1200 ELSE IF(T1<266)*(T1>236)THEN1220
1074 IF(T1<311)*(T1>282)THEN1240 ELSE IF(T1<357)*(T1>327)THEN1260
1075 IF(T1<403)*(T1>373)THEN1280 ELSE IF(T1<479)*(T1>419)THEN1000 ELSE GOTO 1070
1120 REM *** WPN A SINGLE
1130 GOSUB1820:GOSUB1310:GOSUB1330
1135 IF S$="C"THEN1130 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL A WITH PEN"
1136 GOSUB2350:GOSUB1870:GOSUB1310:GOSUB1330:GOTO1135
1140 REM *** WPN B SINGLE
1150 GOSUB1880:GOSUB1310:GOSUB1330
1155 IF S$="C"THEN1150 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL B WITH PEN"
1156 GOSUB2350:GOSUB1940:GOSUB1310:GOSUB1330:GOTO1155
1160 REM *** WPN C SINGLE
1170 GOSUB1950:GOSUB1310:GOSUB1330
1175 IF S$="C"THEN1170 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL C WITH PEN"
1176 GOSUB2350:GOSUB2010:GOSUB1310:GOSUB1330:GOTO1175
1180 REM *** WPN D SINGLE
1190 GOSUB2020:GOSUB1310:GOSUB1330
1195 IF S$="C"THEN1190 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL D WITH PEN"
1196 GOSUB2350:GOSUB2070:GOSUB1310:GOSUB1330:GOTO1195
1200 REM *** WPN E SINGLE
1210 GOSUB2080:GOSUB1310:GOSUB1330
1215 IF S$="C"THEN1210 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL E WITH PEN"
1216 GOSUB2350:GOSUB2120:GOSUB1310:GOSUB1330:GOTO1215
1220 REM *** WPN F SINGLE
1230 GOSUB2130:GOSUB1310:GOSUB1330
1235 IF S$="C"THEN1230 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL F WITH PEN"
1236 GOSUB2350:GOSUB2180:GOSUB1310:GOSUB1330:GOTO1235
1240 REM *** WPN G SINGLE
1250 GOSUB2190:GOSUB1310:GOSUB1330
1255 IF S$="C"THEN1250 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL G WITH PEN"
1256 GOSUB2350:GOSUB2230:GOSUB1310:GOSUB1330:GOTO1255
1260 REM *** WPN H SINGLE
1270 GOSUB2240:GOSUB1310:GOSUB1330
1275 IF S$="C"THEN1270 ELSE IF S$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL H WITH PEN"
1276 GOSUB2350:GOSUB2280:GOSUB1310:GOSUB1330:GOTO1275
1280 REM *** WPN I SINGLE
1290 GOSUB2290:GOSUB1310:GOSUB1330
1295 IF S$="C"THEN1290 ELSE IFS$="N"THEN PN=PN+1:PRINT E$;"PLACE NEW ELL I WITH PEN"
```

```
1290 GOSUB2350:GOSUB2330:GOSUB1310:GOSUB1320:GOTO1295
1300 REM *** SINGLE WPN ENGAGEMENT PRINT COORD SUBROUTINE
1310 Z1=460-(PN*12):PRINT Z$;"OA1";"~U010";Z1;PN" X"PX" Y"PY;Z$;"OA0"
1320 PRINT E$:RETURN
1330 REM *** DECISION:CONTINUE THIS PT OR ADJ A NEW PT
1331 PRINT E$;"CONTINUE THIS PT?   ADJ NEW PT?    ALL POINTS COMPLETE?"
1332 PRINT"~C1~F~G+":PLOT57,473,87,450,214,473,254,450,351,473,391,490:PRINT C$
1333 PRINT"~C4~L~U057472CONTINUE~U214472NEW~U351472COMPLETE":GOSUB2350
1334 IF(T1<87)*(T1>57)THEN S$="C":RETURN ELSE IF(T1<254)*(T1>214)THEN S$="N":RETURN
1335 IF(T1<391)*(T1>351)THEN 1000 ELSE GOTO 1331
1390 REM *** PARAMETER ASSIGNMENT SUBROUTINE
1400 REM *** QUADRANT FOR AZ OF FIRE FOR X OR Y DEVIATION =0
1410 XD=TX-WX:YD=TY-WY:ON ERROR GOTO 1460:A=ATN(ABS(XD)/ABS(YD)):ON ERROR GOTO 0
1415 IF XD=0 THEN 1430 ELSE IF YD=0 THEN1460
1420 GOTO 1500
1430 IF YD>0 THEN 1440 ELSE IF YD<0 THEN 1450
1440 WF=0:RETURN
1450 WF=PI:RETURN
1460 IF XD>0 THEN 1470 ELSE IF XD<0 THEN 1480
1470 WF=PI/2:RETURN
1480 WF=PI/2*3:RETURN
1490 REM *** QUADRANT FOR AZ OF FIRE FOR NONZERO X OR Y DEVITATION
1500 IF XD>0 THEN1510 ELSE IF XD<0 THEN 1520
1510 IF YD>0 THEN 1530 ELSE IF YD<0 THEN 1540
1520 IF YD<0 THEN 1550 ELSE IF YD>0 THEN 1560
1530 WF=A:RETURN
1540 WF=PI-A:RETURN
1550 WF=PI+A:RETURN
1560 WF=2*PI-A:RETURN
1570 REM *** COMPUTE ELLIPSE TILT AND RANGE TO TGT
1580 WT=WF+PI/2:WR=SQR(XD^2+YD^2)
1590 REM *** COMPUTE DELIVERY ELLIPSE PARAMETERS PED(W3) PER(W4) SCALED VALUES
1600 IF(WR>0)*(WR<=16000) THEN 1620
1610 IF(WR>16000)*(WR<=28000) THEN 1630 ELSE GOTO1640
1620 W3=(150+6.25*WR/1000)/20:W4=(100+3.125*WR/1000)/20:GOTO1660
1630 W3=(250+16.666*(WR-16000)/1000)/20:W4=(150+8.333*(WR-16000)/1000)/20:GOTO1660
1640 W3=(450+50*(WR-28000)/1000)/20:W4=(250+21.428*(WR-28000)/1000)/20:GOTO1660
1650 REM *** EFFECTS PATTERN ELLIPSE PARAMETERS (W5=SEMIMAJOR,W6=SEMIMINOR AXIS)
```

```
1660 IF(WR>=0)*(WR<=26000) THEN W5=(80+1.923*WR/1000)/20:GOTO1680
1670 IF WR>26000 THEN W5=(130-1.11*(WT-26000)/1000)/20
1680 W6=(80+.857*WR/1000)/20:RETURN
1690 REM *** PLOT/ERASE ROUTINE FOR DELIVERY ELLIPSE
1700 PRINT Z$;"OA1";"~G("
1710 FOR TH= 0 TO PP STEP D
1720 XT=P3*SIN(TH):YT=P4*COS(TH):GOSUB1800
1725 IF XP<0 THEN 1729 ELSE IF XP>511 THEN 1729
1726 IF YP<0 GOTO 1729
1728 PLOT XP,YP
1729 NEXT TH
1730 PRINT C$;"~C4":RETURN
1740 REM *** PLOT/ERASR ROUTINE FOR EFFECTS PATTERN ELLIPSE
1750 PRINT"~G("
1760 FOR TH= 0 TO PP STEP D
1770 XT=P5*SIN(TH):YT=P6*COS(TH):GOSUB1800
1775 IF XP<0 THEN NEXT TH ELSE IF XP>511 THEN NEXT TH
1776 IF YP<0 THEN NEXT TH
1778 PLOT XP,YP
1779 NEXT TH
1780 PRINT C$;"~C4":RETURN
1790 REM *** ROTATION OF AXIS FOS ELLIPSE TILT SUBROUTINE
1800 XP=(XT*SIN(PT)-YT*COS(PT))+P1:YP=(XT*COS(PT)+YT*SIN(PT))*1.414+P2:RETURN
1810 REM *** ADJUSTMENT SUBROUTINES TO ADJ ELLIPSE LOCATIONS
1820 REM *** ADJ A
1830 PRINT E$;"PLACE NEW A CTR WITH PEN";Z$;"OA1":GOSUB2350
1840 REM *** ERASE OLD A
1850 P1=A1:P2=A2:P3=A3:P4=A4:P5=A5:P6=A6:PT=AT:PRINT"~C1":GOSUB1690
1855 PRINT "~C1":GOSUB1740
1860 REM *** NEW A
1870 P1=T1:P2=T2:A1=T1:A2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
1880 REM *** ADJ B
1890 PRINT E$;"PLACE NEW B CTR WITH PEN";Z$;"OA1":GOSUB2350
1900 REM *** ERASE OLD B
1910 P1=B1:P2=B2:P3=B3:P4=B4:P5=B5:P6=B6:PT=BT:PRINT"~C1":GOSUB1690
1920 PRINT"~C1":GOSUB1740
1930 REM *** NEW B
1940 P1=T1:P2=T2:B1=T1:B2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
```

```
1950 REM *** ADJ C
1960 PRINT E$;"PLACE NEW C CTR WITH PEN";Z$;"OA1":GOSUB2350
1970 REM *** ERASE OLD C
1980 P1=C1:P2=C2:P3=C3:P4=C4:P5=C5:P6=C6:PT=CT:PRINT"~C1":GOSUB1690
1990 PRINT"~C1":GOSUB1740
2000 REM *** NEW C
2010 P1=T1:P2=T2:C1=T1:C2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2020 REM *** ADJ D
2025 PRINT E$;"PLACE NEW D CTR WITH PEN";Z$;"OA1":GOSUB2350
2030 REM *** ERASE OLD D
2040 P1=D1:P2=D2:P3=D3:P4=D4:P5=D5:P6=D6:PT=DT:PRINT"~C1":GOSUB1690
2050 PRINT"~C1":GOSUB1740
2060 REM *** NEW D
2070 P1=T1:P2=T2:D1=T1:D2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2080 REM *** ADJ E
2085 PRINT E$;"PLACE NEW E CTR WITH PEN";Z$;"OA1":GOSUB2350
2090 REM *** ERASE OLD E
2100 P1=E1:P2=E2:P3=E3:P4=E4:P5=E5:P6=E6:PT=ET:PRINT"~C1":GOSUB1690
2110 PRINT"~C1":GOSUB1740
2120 P1=T1:P2=T2:E1=T1:E2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2130 REM *** ADJ F
2135 PRINTE$;"PLACE NEW F CTR WITH PEN";Z$;"OA1":GOSUB2350
2140 REM *** ERASE OLD F
2150 P1=F1:P2=F2:P3=F3:P4=F4:P5=F5:P6=F6:PT=FT:PRINT"~C1":GOSUB1690
2160 PRINT"~C1":GOSUB1740
2170 REM *** NEW F
2180 P1=T1:P2=T2:F1=T1:F2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2190 REM *** ADJ G
2195 PRINT E$;"PLACE NEW G CTR WITH PEN";Z$;"OA1":GOSUB2350
2200 P1=G1:P2=G2:P3=G3:P4=G4:P5=G5:P6=G6:PT=GT:PRINT"~C1":GOSUB1690
2210 PRINT"~C1":GOSUB1740
2220 REM *** NEW G
2230 P1=T1:P2=T2:G1=T1:G2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2240 REM *** ADJ H
2245 PRINT E$;"PLACE NEW H CTR WITH PEN";Z$;"OA1":GOSUB2350
2250 P1=H1:P2=H2:P3=H3:P4=H4:P5=H5:P6=H6:PT=HT:PRINT"~C1":GOSUB1690
2260 PRINT"~C1":GOSUB1740
2270 REM *** NEW H
```

```
2280 P1=T1:P2=T2:H1=T1:H2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2290 REM *** ADJ I
2295 PRINT E$;"PLACE NEW I CTR WITH PEN";Z$;"0A1":GOSUB2350
2300 P1=I1:P2=I2:P3=I3:P4=I4:P5=I5:P6=I6:PT=IT:PRINT"~C1":GOSUB1690
2310 PRINT"~C1":GOSUB1740
2320 REM *** NEW I
2330 P1=T1:P2=T2:I1=T1:I2=T2:GOSUB1690:PRINT"~C0":GOSUB1740:GOSUB2400:RETURN
2340 REM *** READ LIGHTPEN HIT SUBROUTINE
2350 OUT &H90,0
2360 ON ERROR #2 GOTO 2380
2370 GOTO 2370
2380 IF ERR=24 THEN T1=CURSX(4):T2=CURSY(4) ELSE ON ERROR #0 GOTO 0
2390 OUT &H90,0:RESUME 2391
2391 RETURN
2400 REM *** COORD CONVERSION SUBROUTINE
2410 PX=(P1-255)*20+TX:PY=(P2-255)/1.414*20+TY:RETURN
2420 REM *** DEFINE IRREGULAR SHAPED TGT WITH LIGHTPEN
2430 PRINT E$;"USE PEN TO DEFINE IRREGULAR TGT.  DESIGNATE WHITE BOX WHEN COMPLETE."
2440 PRINT Z$;"0A1";"~C7~U255255+~F~G+":PLOT 400,400,440,440
2450 PRINT"~L~G(~C1":PLOT 255,255:OUT &H90,0:ON ERROR #2 GOTO 2470
2460 GOTO 2460
2470 IF ERR=24 THEN T1=CURSX(4):T2=CURSY(4) ELSE ON ERROR #0 GOTO 0
2480 IF(T1<440)*(T1>400) THEN IF(T2<440)*(T2>400) THEN 2500
2490 PLOT T1,T2:PRINT"~C7":OUT &H90,0:RESUME
2500 OUT &H90,0:RESUME 2510
2510 PRINT"~C1~F~G+":PLOT 400,400,440,440:PRINT"~L~C4";C$;Z$;"0A0":GOTO 320
2520 REM *** SELECT WPN BY LIGHTPEN SUBROUTINE
2530 PRINT E$;"SPECIFY,WITH PEN,ONE WPN TO ADJUST. DESIGNATE *NONE*IF COMPLETE."
2540 PRINT"~C1~G+":PLOT16,473,46,490,62,473,92,490,108,473,138,490,154,473,184,490,
     190,473,220,490
2550 PLOT 236,473,266,490,282,473,311,490,327,473,357,490,373,473,403,490,419,473,479,
     490
2560 PRINT C$;"~C4~U031472A~U077472B~U123472C~U169472D~U205472E~U251472F~U297472G";
2570 PRINT"~U342472H~U388472I~U434472NONE"
2580 GOSUB2350:PRINT E$:RETURN
2590 END
```

Appendix B

Photographs of Selected Program Features

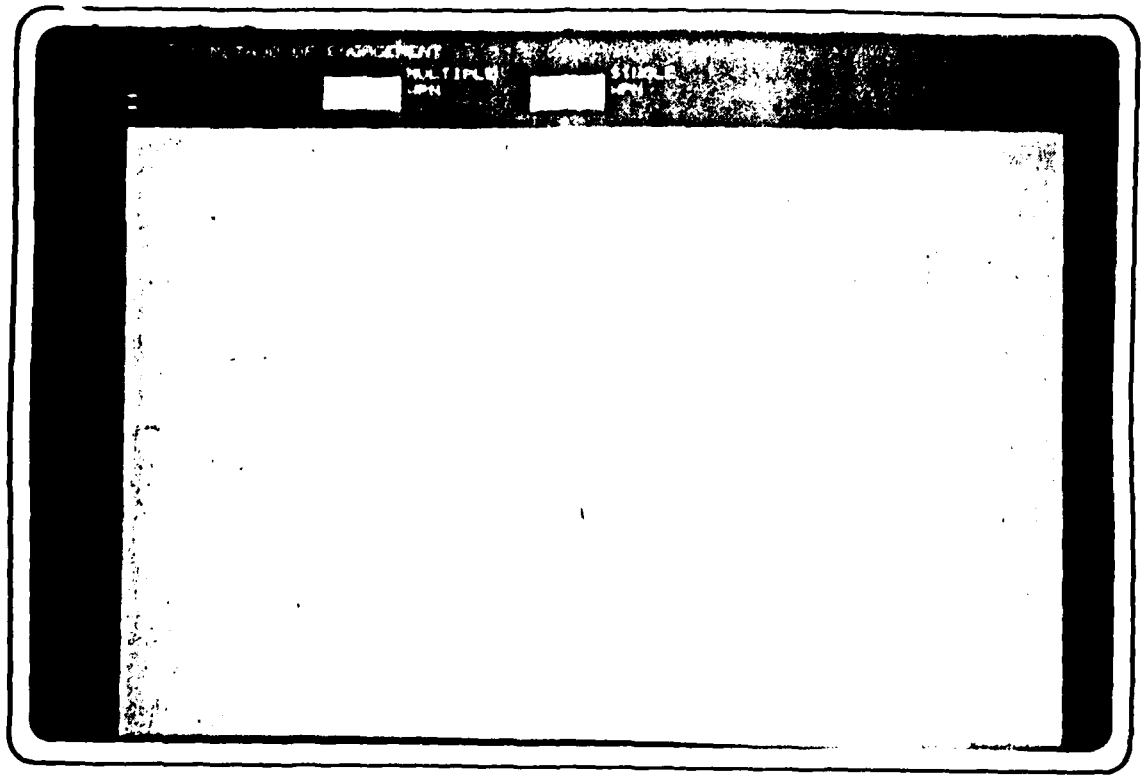


Photo 1

Circular Target Option (Keyboard Data Input)

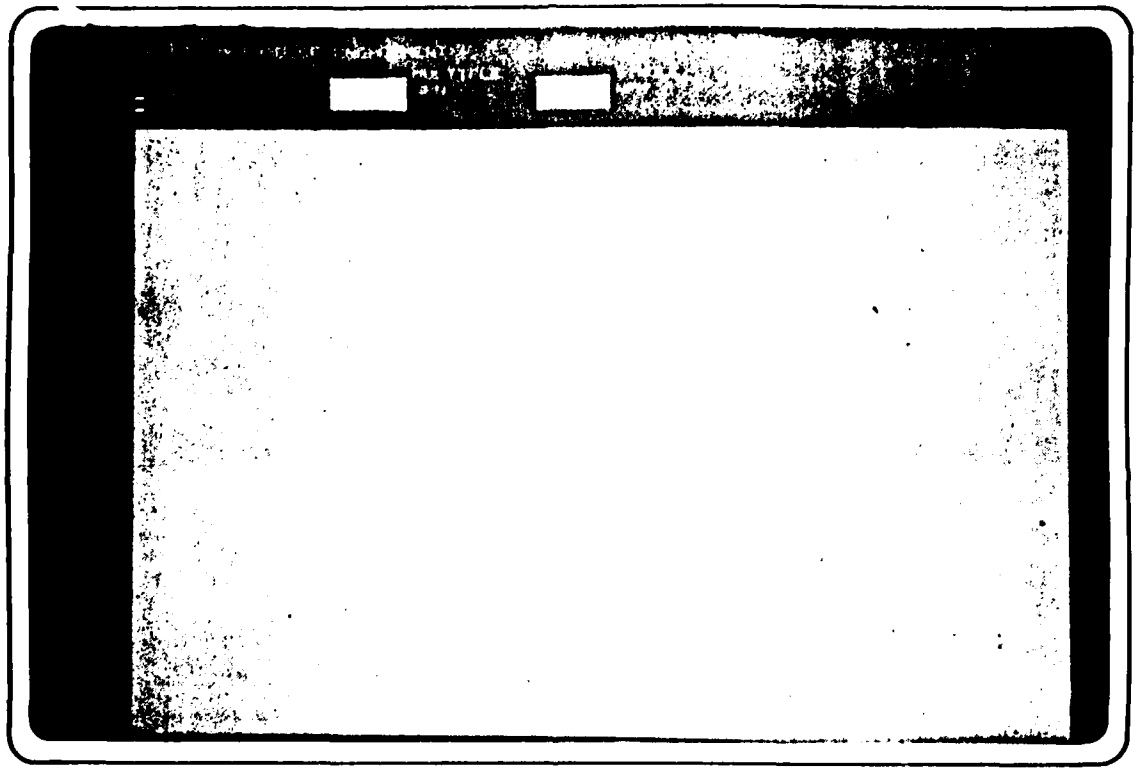


Photo 2

Rectangular Target Option (Keyboard Data Input)

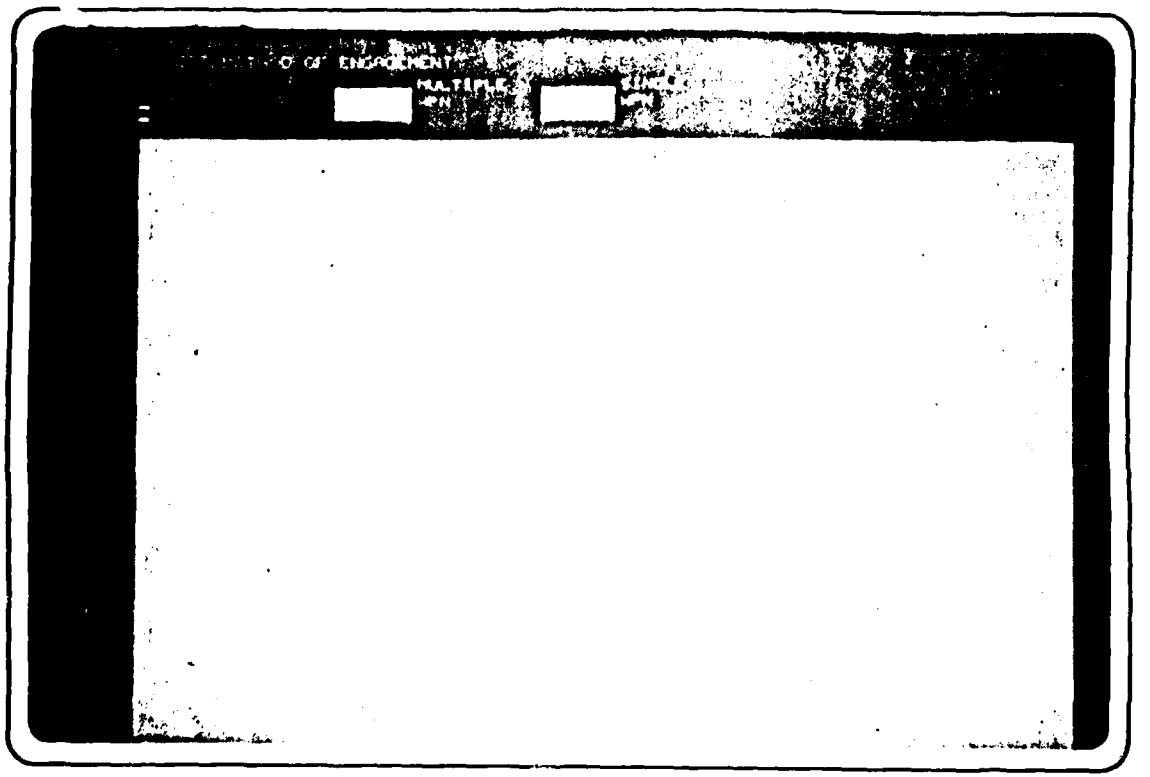


Photo 3

Irregularly Shaped Target Option (Drawn With Light Pen)

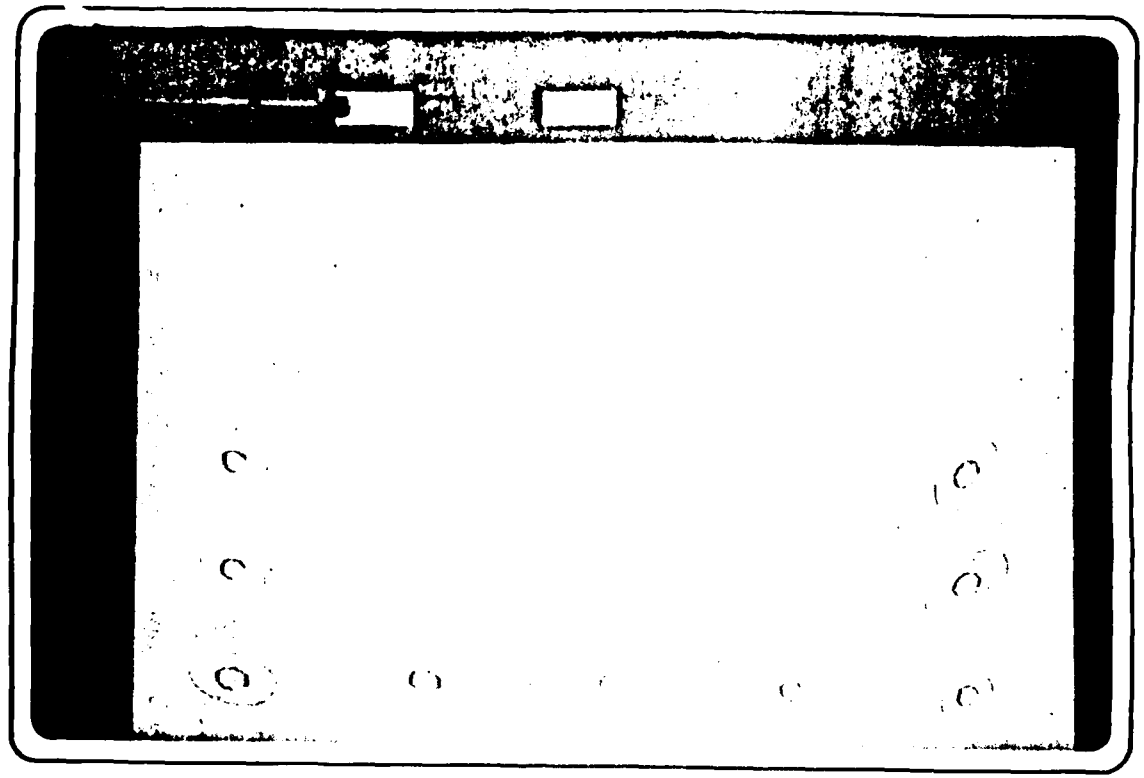


Photo 4

Example of an Initial Display Following Target Definition (All nine weapons in position and in range of target center; Light Pen designating Multiple Wpn option)

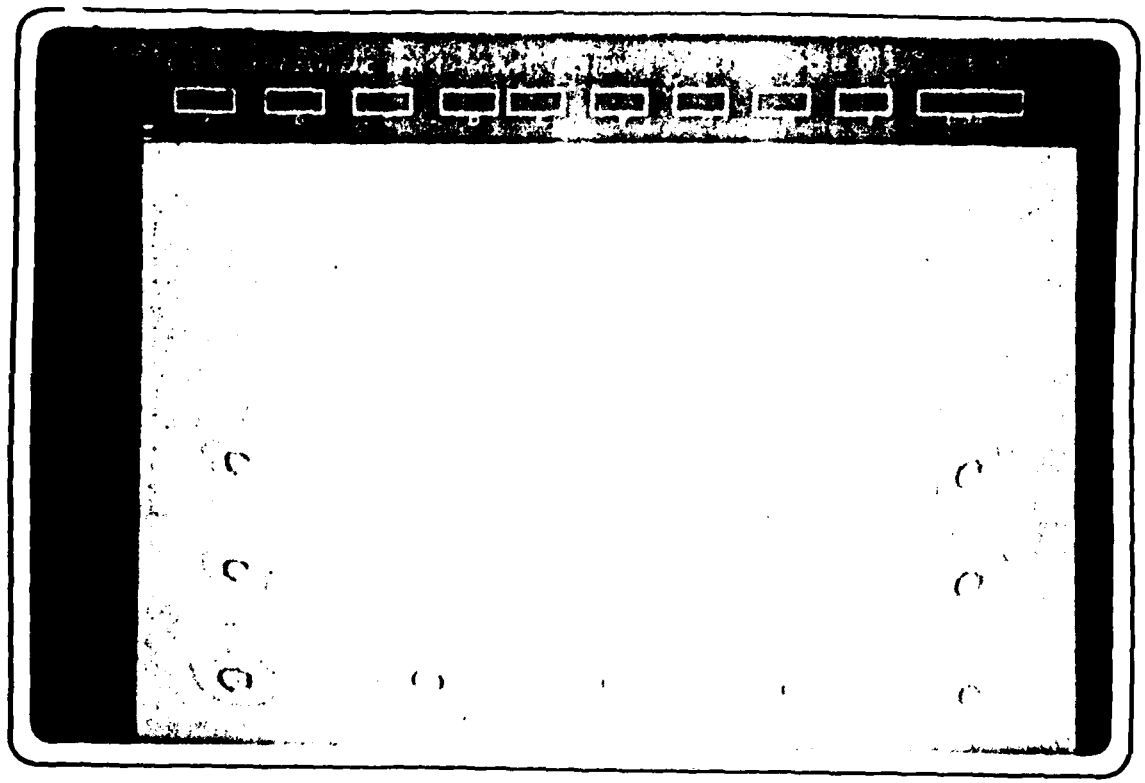


Photo 5

Computer Requests Designation of First Wpn for
CAE Adjustment onto Target Area

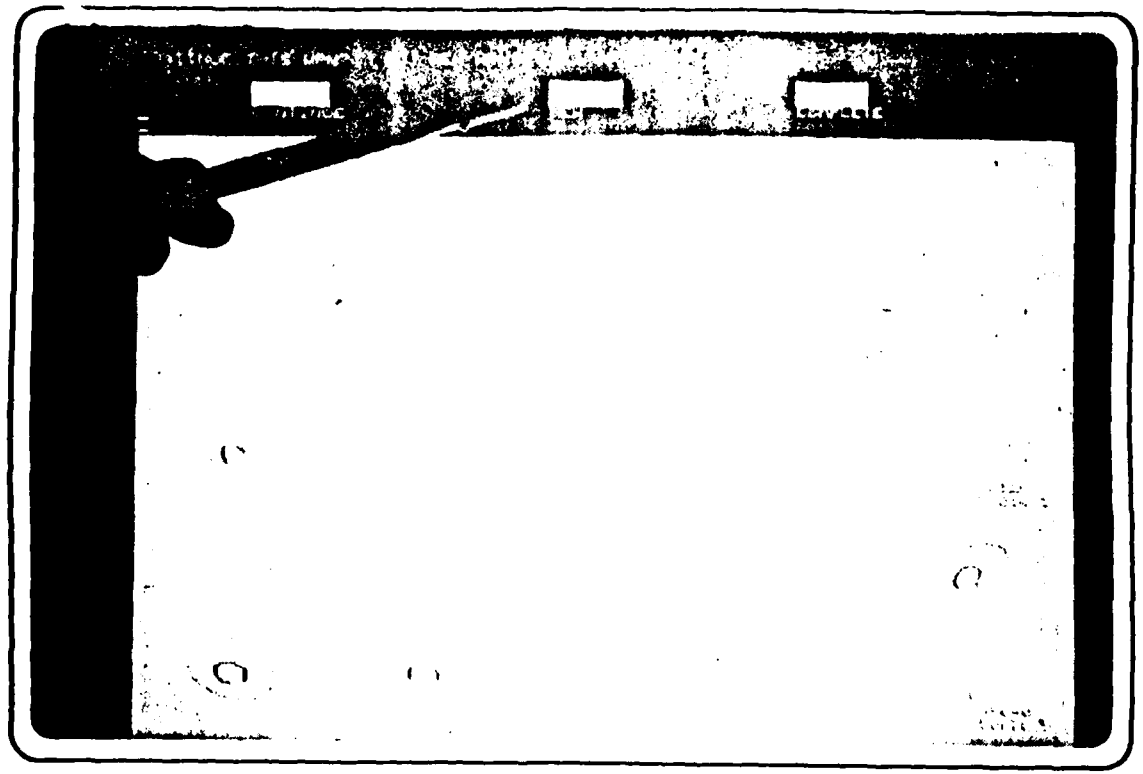


Photo 6

Five Wpns (B,E,F,G,I) Have Been Placed.
User States Another (new) Wpn Will Be
Adjusted (see next photo)

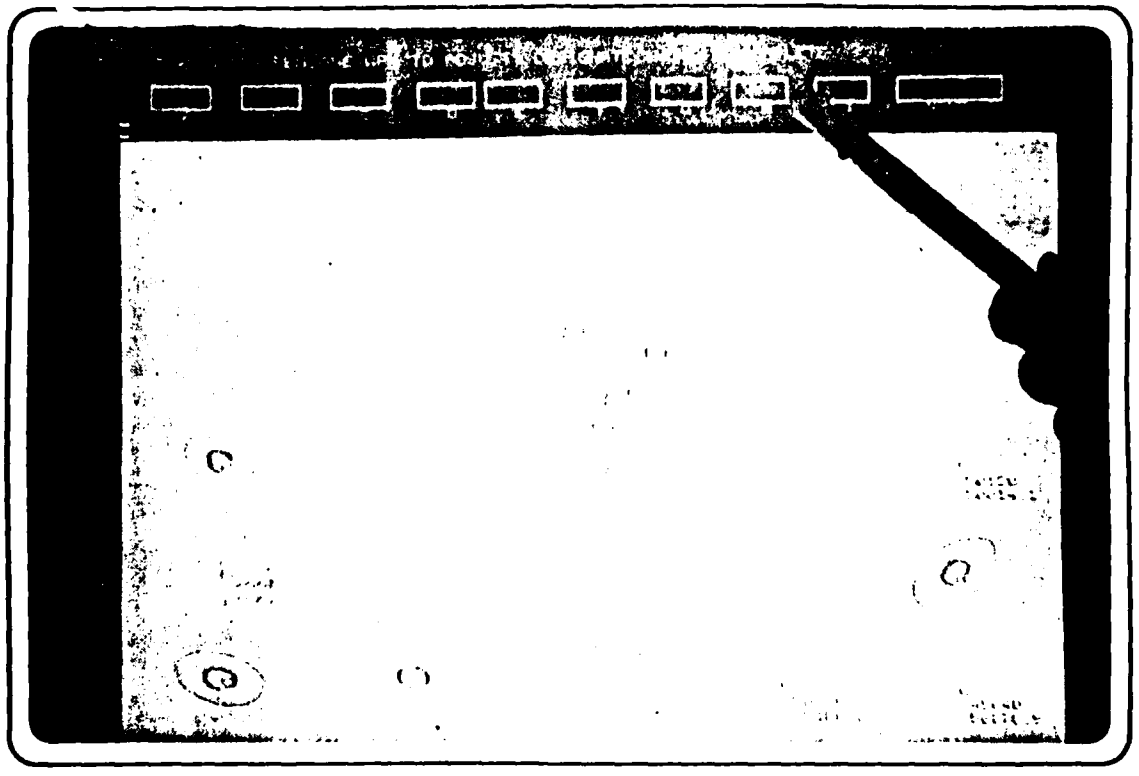


Photo 7

User Specifies H as the New Wpn for Adjustment in Solving the Problem.

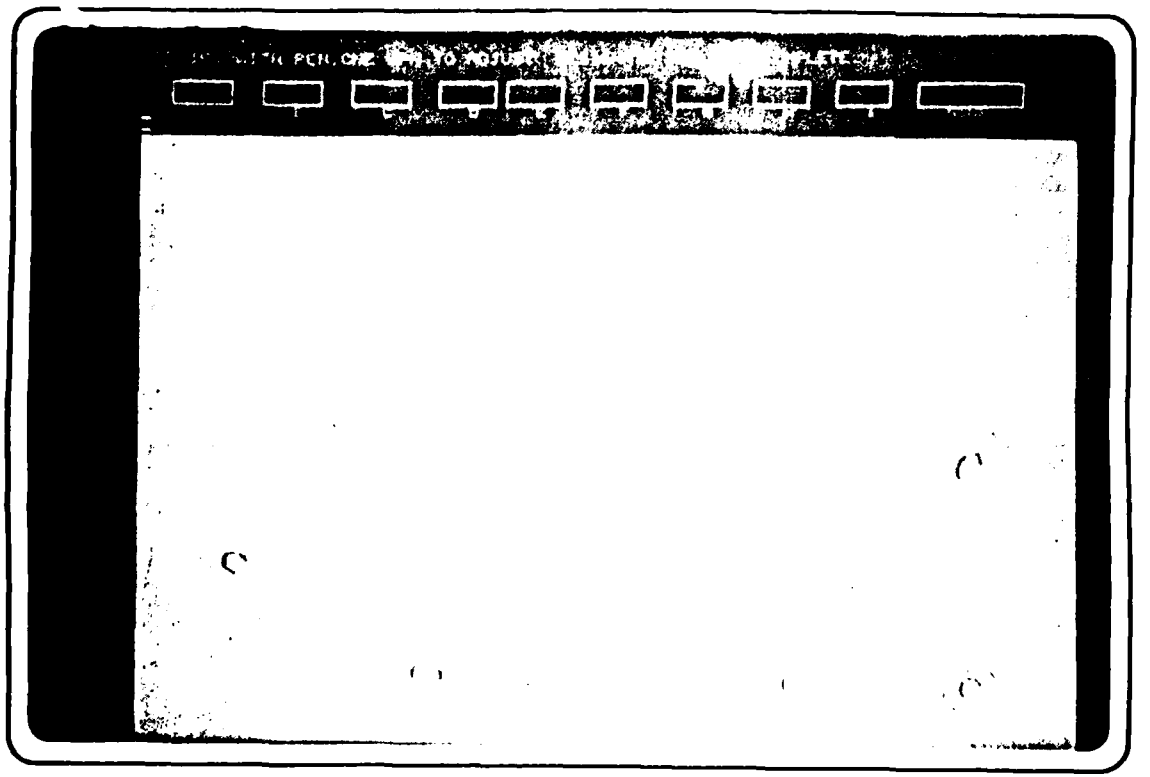


Photo 8

Example of a Linear Target with Initial Display (A,C,H are either out of range or unavailable) Light Pen Selects G as the Wpn for a Single Wpn Engagement.

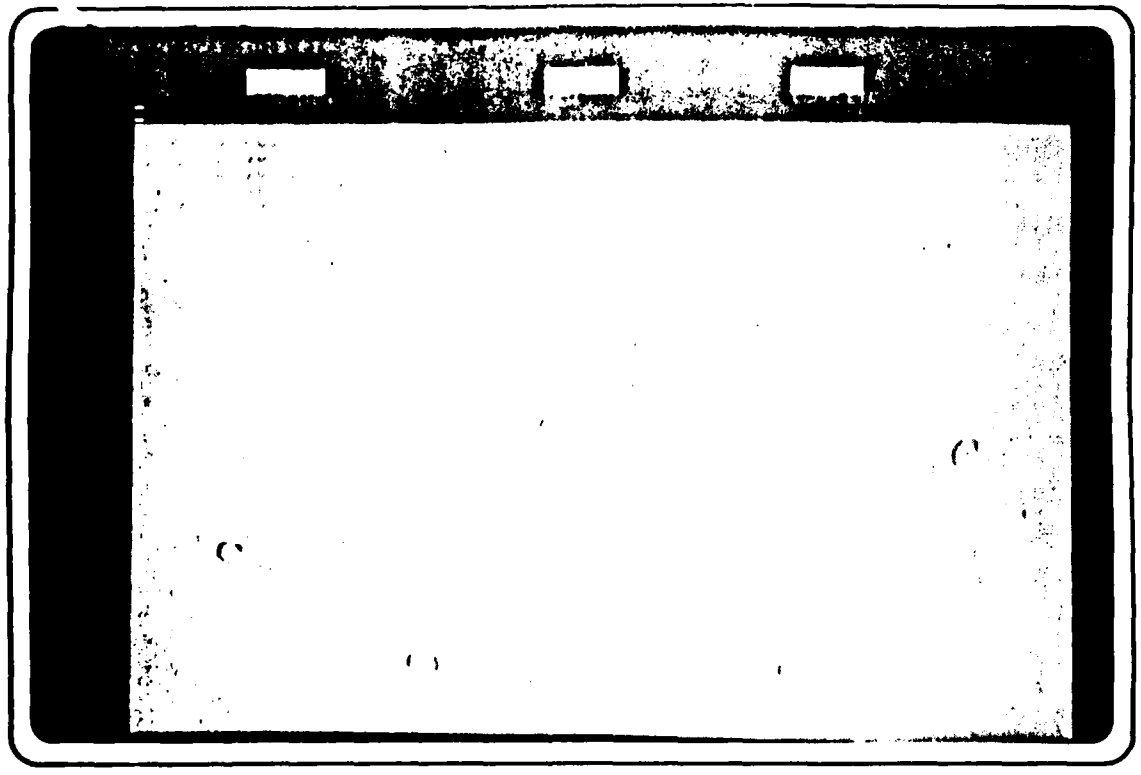


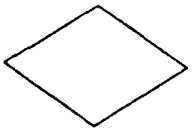
Photo 9

Example of a Single Wpn Engagement

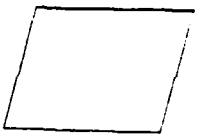
Appendix C

Interaction Flow Diagram

LEGEND



User Decision

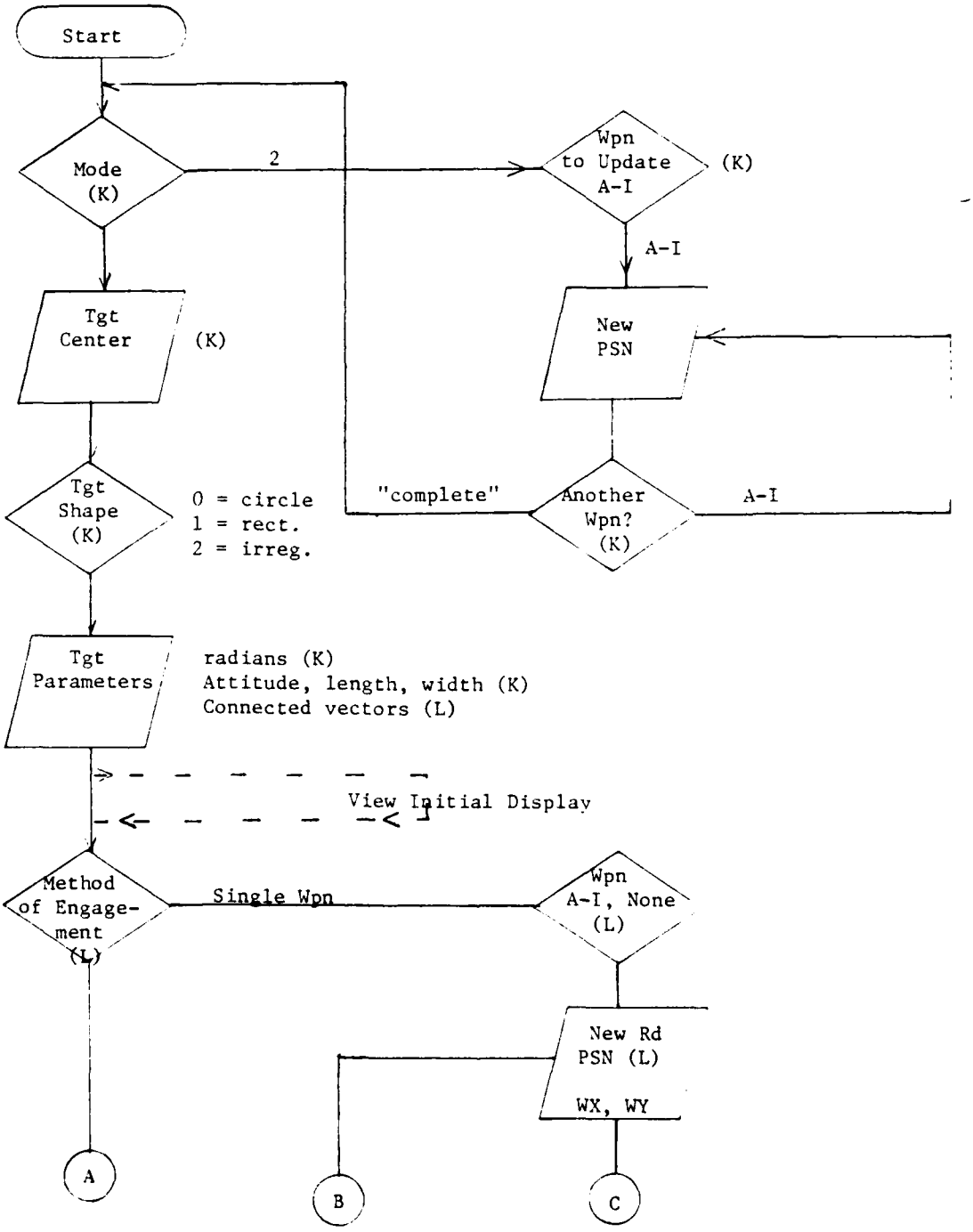


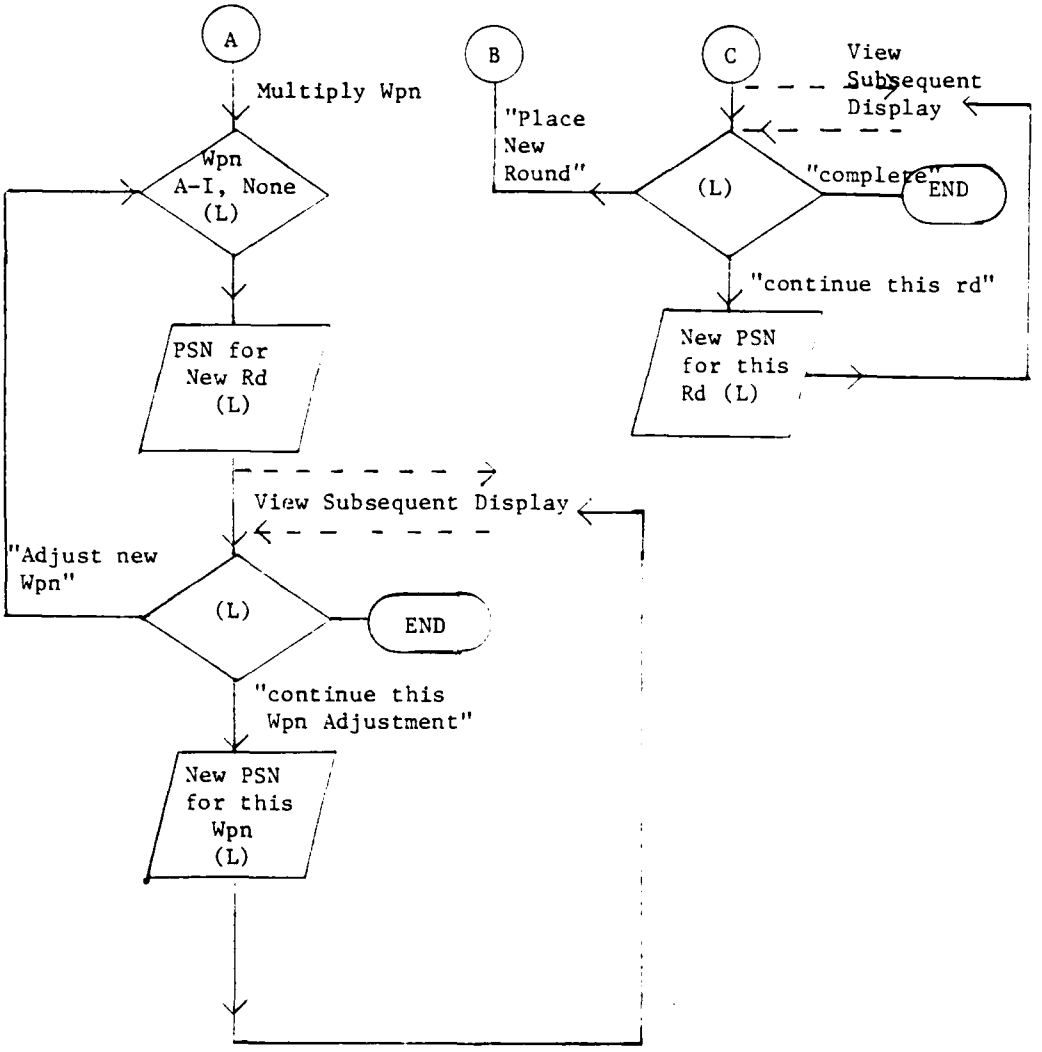
User Data Input

( ) Method of Entry

(K) = Keyboard Input

(L) = Light Pen Input


Start
Mode (K)
2
Wpn to Update A-I
(K)
A-I
Tgt Center
(K)
New PSN
Tgt Shape (K)
0 = circle
1 = rect.
2 = irreg.
"complete"
Another Wpn? (K)
A-I
Tgt Parameters
radians (K)
Attitude, length, width (K)
Connected vectors (L)
View Initial Display
Method of Engage-ment (L)
Single Wpn
Wpn A-I, None (L)
New Rd PSN (L)
WX, WY
A
B
C


A
Multiply Wpn
Wpn
A-I, None
(L)
PSN for
New Rd
(L)
B
"Place
New
Round"
C
View
Subsequent
Display
(L)
"complete"
END
"continue this rd"
New PSN
for this
Rd (L)
View Subsequent Display
"Adjust new
Wpn"
(L)
END
"continue this
Wpn Adjustment"
New PSN
for this
Wpn
(L)

Appendix D

User Guidelines

The following guidelines apply to the program as it appears in the document, i.e., the two methods of engagement as discussed in Section III-E. The more flexible method (multiple weapon, multiple rounds per weapon) would, of course, require more flexible guidelines.

(1) Grids should be input exactly as requested: one meter accuracy with a comma between Easting and Northing.

(2) Large rectangular targets should normally be attacked with a single weapon. Generally consider only weapons whose CAE/EPE major axis is nearly parallel to the target's longest axis. Of these weapons, choose the one with the smallest CAE. Arrange aim points in rows parallel with the target's long axis.

(3) Large circular targets will normally be best attacked with a multiple weapon approach. Large CAE weapons should be near the center with the smaller CAE weapons on the boundaries such that the CAE major axis is parallel to the target at the target's nearest boundary point to CAE center.

(4) Small circular targets should, of course, be fired upon by small CAE weapons: multiple weapons if there are several small CAE weapons or a single weapon if there is one obvious best CAE weapon.

(5) Irregularly shaped targets (excluding roads, rivers, etc.) should generally be attacked with multiple weapons if their boundaries are extremely irregular. A target such as a road or a river with one general direction (no drastic bends) should be attacked as in paragraph (2) above. Large, well behaved irregular boundary targets should be attacked in a manner such as rectangular or circular - depending upon what it most closely approximates.

(6) In general, very small refinements to a round's position should be avoided due to time factors and the probabilistic nature of the problem from the start.

(7) In general, overlaps of CAE's should be avoided and CAE's should remain as much as possible within the target boundaries. When overlaps are necessary, they should be done so as to minimize overlap.

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